FORM PTO-1390 (Modified) (REV 11-98) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER	U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 1.5)
14148	09/719242

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/IB99/01002	3 June 1999 (03.06.99)	8 June 1998 (08.06.98)

TITLE OF INVENTION

DETECTOR FOR IONISING RADIATION

APPLICANT(S) FOR DO/EO/US

Ricardo Simon Sussmann, Geoffrey Alan Scarsbrook and Andrew David Gary Stewart

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210)
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☒ Certificate of Mailing by Express Mail
20. ☒ Other items or information:

Courtesy copy of international application
One (1) page of drawing

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 1.5)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
09/719242	PCT/IB99/01002	14148

21. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS PTO USE ONLY
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO and International Search Report not prepared by the EPO or JPO	$1,000.00	
☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but Internation Search Report prepared by the EPO or JPO	$860.00	
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO	$710.00	
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4)	$690.00	
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4)	$100.00	
ENTER APPROPRIATE BASIC FEE AMOUNT =		$860.00
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).		$130.00

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	* 14 - 20 =	0	x $18.00	$0.00	
Independent claims	* 1 - 3 =	0	x $80.00	$0.00	
Multiple Dependent Claims **(check if applicable)**.			☐	$0.00	
TOTAL OF ABOVE CALCULATIONS =				$990.00	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable)**.			☐	$0.00	
SUBTOTAL =				$990.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).			+	$0.00	
TOTAL NATIONAL FEE =				$990.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).**			☐	$0.00	
TOTAL FEES ENCLOSED =				$990.00	
				Amount to be: refunded	$
				charged	$

* Claim calculation based on claims amended by Preliminary Amendment being filed concurrently herewith

☒ A check in the amount of **$990.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees.
A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **19-1013** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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Leopold Presser
NAME

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REGISTRATION NUMBER

December 8, 2000
DATE

09/719242

CERTIFICATE OF MAILING BY "EXPRESS MAIL" (37 CFR 1.10) Applicant(s): **Ricardo S. Sussmann et al.**			Docket No. **14148**
Serial No. **Unassigned**	Filing Date **Herewith**	Examiner	Group Art Unit

Invention: **DETECTOR FOR IONISING RADIATION**

I hereby certify that the following correspondence:

Transmittal Letter to the U.S. Designated/Elected Office Concerning a Filing under 35 U.S.C. 371

(Identify type of correspondence)

is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 in an envelope addressed to: The Assistant Commissioner for Patents, Washington, D.C. 20231

December 8, 2000
(Date)

Mishelle Mustafa
(Typed or Printed Name of Person Mailing Correspondence)

(Signature of Person Mailing Correspondence)

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Note: Each paper must have its own certificate of mailing.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Ricardo S. Sussmann et al. **Examiner**:

Serial No: Unassigned **Art Unit**:

Filed: Herewith **Docket**: 14148

For: DETECTOR FOR IONISING RADIATION **Dated**: December 8, 2000

Assistant Commissioner for Patents
United States Patent and Trademark Office
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Sir:

In connection with the filing of the above-identified application, kindly enter the following preliminary amendments.

AMENDMENTS

IN THE CLAIMS:

Please amend claims 4, 8-11, 13 and 14 as follows:

Claim 4, line 1, amend "any one of claims 1 to 3" to read --claim 1--;

Claim 8, line 1, amend "any one of claims 1 to 7" to read --claim 1--;

CERTIFICATE OF MAILING UNDER 37 C.F.R. §1.8(a)

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231, on December 8, 2000.

Dated: December 8, 2000

Mishelle Mustafa

Claim 8, line 1, amend "any one of claims 1 to 7" to read --claim 1--;

Claim 9, line 1, amend "any one of claims 1 to 8" to read --claim 1--;

Claim 10, line 1, amend "any one of claims 1 to 9" to read --claim 1--;

Claim 11, line 1, amend "any one of claims 1 to 10" to read --claim 1--;

Claim 13, line 1, delete "or claim 12"; and

Claim 14, lines 1-2, amend "any one of claims 1 to 13" to read --claim 1--.

REMARKS

As originally prepared, claims 8-11, 13 and 14 did not comply with the multiple dependent claim style specified by U.S. law. The above amendments have been made to delete all multiple dependencies. It is respectfully submitted that no new subject matter has been added by way of these amendment.

It is respectfully requested that the above amendments be entered before an action on the merits is issued.

Respectfully submitted,

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09/719242

WO 99/64892 1/PRTS PCT/IB99/01002

JC01 Rec'd PCT/PTO 08 DEC 2000

DETECTOR FOR IONISING RADIATION

BACKGROUND OF THE INVENTION

This invention relates to a detector for ionising radiation.

Radiation detectors comprising diamond have been proposed which are optimised for the detection of different types of radiation. For example, radiation comprising heavy particles such as alpha particles is usually absorbed close to the surface of a detector element, so that a radiation detector optimised for the detection of such radiation can be relatively thin. On the other hand, radiation such as beta particles, x-rays or gamma-rays tends to penetrate the material of a detector element to a greater depth and to be absorbed substantially uniformly throughout the bulk of the detector element.

It is an object of the invention to provide a single detector which is able to detect such different types of radiation optimally, or which can provide different types of information about a single type of radiation.

SUMMARY OF THE INVENTION

According to the invention there is provided a detector for ionising radiation comprising at least first and second diamond detector elements connected electrically to a common contact, with respective first and second contacts connected to the first and second detector elements, so that the detector simultaneously provides first and second output signals corresponding to radiation incident on the detector elements.

Preferably the first and second detector elements are optimised for the detection of different types of radiation, or for the detection of different parameters of a particular type of radiation.

The first and second detector elements may be formed as respective first and second layers of diamond material in contact with a common metallic or semi-conductor layer.

In a preferred embodiment of the invention, the first layer comprises a relatively thick layer of diamond material and the second layer comprises a relatively thin layer of diamond material.

The common metallic or semi-conductor layer may comprise a material selected from the group consisting of titanium, tungsten, molybdenum and boron doped diamond.

The first layer may have a thickness of between 0.3 mm and 1.5 mm and a collection distance of at least 20 μm, preferably at least 50 μm, and even more preferably a distance of 300 μm or more. The first layer may be optimised for the detection of beta particles, x-rays and gamma rays.

The second layer may have a thickness of between 10 μm and 40 μm and may be optimised for the detection of alpha particles.

The detector may further include respective conductive layers on the outer surfaces of the first and second layers of diamond material, which preferably comprise a material selected from the group consisting of titanium, tungsten, molybdenum and boron doped diamond.

Respective active contacts may be connected to the conductive layers.

The invention also extends to a radiation detector apparatus comprising a detector as defined above, and further comprising bias means arranged to apply respective bias voltages to the first and second diamond detector elements, and first and second amplifiers having inputs connected to the first and second diamond detector elements and arranged to generate respective first and second amplified output signals corresponding to radiation incident on the detector elements

BRIEF DESCRIPTION OF THE DRAWING

The drawing is a highly schematic sectional view of a radiation detector according to the invention, with associated electronic circuitry.

DESCRIPTION OF AN EMBODIMENT

The illustrated radiation detector comprises a first, relatively thick diamond layer 10 and a second, relatively thin diamond layer 12 on either side of a layer 14 of metal or semi-conductive material which serves as a common contact or electrode. The layers 10 and 12 are optimised for the detection of different kinds of ionising radiation, so that a single, unitary radiation detector element is provided which can effectively detect different types of radiation. Alternatively, for example, the detector of the invention could be used for the simultaneous or sequential measurement of partial energy loss of a particle (measured in the thin layer 12) and total particle energy (measured in the thick layer 10).

A prototype radiation detector of the invention was manufactured by commencing with the layer 10, which was a layer of high quality diamond produced by chemical vapour deposition (CVD) with a thickness between 0.3 mm and 1.5 mm and a collection distance of 20 μm, but typically at least 50 μm and, depending on the application, possibly up to 300 μm or more.

Collection distance and its determination are known in the art. Radiation such as UV, x-rays and gamma rays impinging on diamond can form electron/hole pairs which drift under an applied voltage between electrodes. Typically, for penetrating radiation such as beta and gamma rays, the electrodes are placed on opposite surfaces of a diamond layer whose thickness is typically 200 - 700 μm, but can range from less than 100 μm to greater than 1000 μm, and the charge carriers (electrons/holes) drift through the thickness of the layer. For highly absorbed radiation which penetrates only a few μm into the diamond, such as alpha radiation or UV radiation with energies near or above that of the band gap, then inter-digitated electrode arrangements on the same face of the diamond layer may be used; this face may be planar or with the electrodes placed in relationship to surface structures such as grooves.

However, the electrons and holes have finite mobilities and lifetimes so they move only a certain distance before recombining. When an event occurs (e.g. impingement of beta particles) which forms charge carriers, then to first order the total signal from the detector depends on the average distance moved by the charge carriers. This charge displacement is a product of the carrier mobility and the applied electric field (which gives the charge drift velocity) and the recombination lifetime of the carriers before trapping or recombination stops its drift. This is the collection distance which can also be considered as the volume of charge swept to the electrode. The purer the diamond (or the lower the level of uncompensated traps) or the lower the level of crystalline imperfections, the higher the mobility of the carriers and/or their lifetimes.

The next step is the application of the conductive layer 14 to the layer 10. The conductive layer can comprise a metal which adheres to CVD diamond, such as titanium (Ti), tungsten (W), molybdenum (Mo) or other suitable metals. Alternatively, the layer 14 can comprise a substantially conductive semi-conductor layer such as boron doped diamond.

The layer 12 is grown by a CVD process on top of the layer 14 to a thickness optimised for the detection of a different form of radiation compared with that for which the layer 10 is optimised. (In the prototype, the layer 10 was optimised for the detection of beta particles, x-rays and gamma-rays, while the layer 12 was optimised for the detection of alpha particles). In the prototype, the layer 12 had a thickness between 10 μm and 40 μm.

An alternative method of forming the radiation detector is to grow the layers 10 and 12 separately, and then to adhere the conductive layer 14 to one of these layers. The free surface of the conductive layer 14 can then be bonded to the other of the layers 10 or 12.

At one edge of the detector element, a small portion of the layer 12 was removed by a known technique such as oxygen plasma etching, ion beam milling/etching or laser ablation to expose a section 16 of the common contact/electrode 14. (Alternatively, at the time the layer 12 is grown, a section of the layer 14 may be masked. This would prevent the layer 12 from growing

on the masked section, rather than having to remove a portion of it after growth.) The section 16 serves as a common ground contact for the respective layers of the detector elements. In addition, conductive layers 18 and 20 were applied to the outer surfaces of the layers 10 and 12, respectively, to permit the connection of respective active contacts 22 and 24. The conductive layers 18 and 20 can comprise the same metal as that used for the layer 14, ie. Ti, W, Mo or other suitable metals.

The respective contacts are used to bias the respective active layers of the device and to connect the detector elements to suitable electronics.

As shown in the Figure, the contact 22 is connected to an input of a charge sensitive or operational preamplifier A_1 via a coupling capacitor C_1 while the contact 24 is connected to the input of a similar amplifier A_2 via a coupling capacitor C_2. Respective bias voltages V_1 and V_2 are applied to the contacts 22 and 24 via resistors R_1 and R_2. Typically, the bias voltages are 0.1 to 3V/μm. The sign of the applied bias voltage (positive or negative) may vary from what is indicated in the Figure, depending on the application and the material selected for the common contact/electrode.

In a variation of the invention, the metal conductive layer 14 can be replaced by a CVD diamond boron doped layer. This has the advantage that the layer 14, and subsequently the layer 12, can both be grown epitaxially on the layer 10, resulting in the layer 12 being of a higher quality. This is because the quality

(for charge collection efficiency) is known to increase with the thickness of the layer. In the case of the above described example, the layer 12 will typically be polycrystalline in nature and will have a large component of the nucleation grain structure, which is known to be of relatively poor quality, whereas in the second example, the layer 12 will start to grow replicating the grain structure of the layer 14, which in turn should replicate that of the layer 10.

There will be a small amount of interaction between the two layers, for example, the generation of a small signal in the layer 12 due to the absorption of beta particles, but this will be in the ratio of the respective thicknesses of the layers 10 and 12, which can be made to be over a factor of 10.

In other applications, it is required to make two simultaneous measurements of the same particle(s) using a transmission detector which measures the partial energy loss in a thin transmission detector (ΔE), and total particle energy in an absorbing detector (E). From accurate measurement of both E and ΔE it is possible to calculate the mass of the particle and thus differentiate between light charged particles which have a similar mass, eg. protons, deuterons, and ^3He ions. In this type of application, the requirement on the transmission detector is that it should be sufficiently thin to allow transmission of the particles of interest, which in certain applications can limit the thickness in a diamond detector to 40 μm or less, making the detector potentially fragile. The dual detector arrangement provides both the measurement of both ΔE and E in one device, and mechanical support for the otherwise fragile ΔE detector. The latter

makes it more robust and suitable for larger areas, and also give the possibility of reducing further its thickness so that the lower energy cutoff is reduced and the energy straggling is improved. In this type of application it is important to select an interlayer of the correct thickness and properties in order to minimise the error introduced to the measure of E_1 but it does avoid the need for two separate contact layers on separate ΔE and E detectors, so that overall the system design is simplified.

The concept of the invention could easily be extended to a device having more that two detector layers. For example, such a device might be used for the detection of more than two different types of radiation of different penetration or energy loss characteristics.

CLAIMS:

1. A detector for ionising radiation comprising a first relatively thick layer of diamond material and a second relatively thin layer of diamond material adjacent to the first layer, the layers being connected electrically to a common contact, the first and second layers being optimised for the detection of different types of radiation or for the detection of different parameters of a particular type of radiation, with respective first and second contacts connected to the first and second layers, so that the detector simultaneously provides first and second output signals corresponding to radiation incident on the detector elements.

2. A detector according to claim 1 wherein the common contact comprises a metallic or semi-conductor layer between the first and second diamond layers.

3. A detector according to claim 2 wherein the common metallic or semi-conductor layer comprises a material selected from the group consisting of titanium, tungsten, molybdenum and boron doped diamond.

4. A detector according to any one of claims 1 to 3 wherein the first layer has a thickness of between 0.3 mm and 1.5 mm.

5. A detector according to claim 4 wherein the first layer has a collection distance of at least 20 μm.

6. A detector according to claim 5 wherein the first layer has a collection distance of at least 50 μm.

7. A detector according to claim 6 wherein the first layer has a collection distance of 300 μm or more.

8. A detector according to any one of claims 1 to 7 wherein the first layer is optimised for the detection of beta particles, x-rays and gamma rays.

9. A detector according to any one of claims 1 to 8 wherein the second layer has a thickness of between 10 μm and 40 μm.

10. A detector according to any one of claims 1 to 9 wherein the second layer is optimised for the detection of alpha particles.

11. A detector according to any one of claims 1 to 10 further including respective conductive layers on the outer surfaces of the first and second layers of diamond material.

12. A detector according to claim 11 wherein the conductive layers comprise a material selected from the group consisting of titanium, tungsten, molybdenum and boron doped diamond.

13. A detector according to claim 11 or claim 12 including respective active contacts connected to the conductive layers.

14. Radiation detector apparatus comprising a detector according to any one of claims 1 to 13, bias means arranged to apply respective bias voltages to the first and second diamond layers, and first and second amplifiers having inputs connected to the first and second diamond layers and arranged to generate respective first and second amplified output signals corresponding to radiation incident on the layers.

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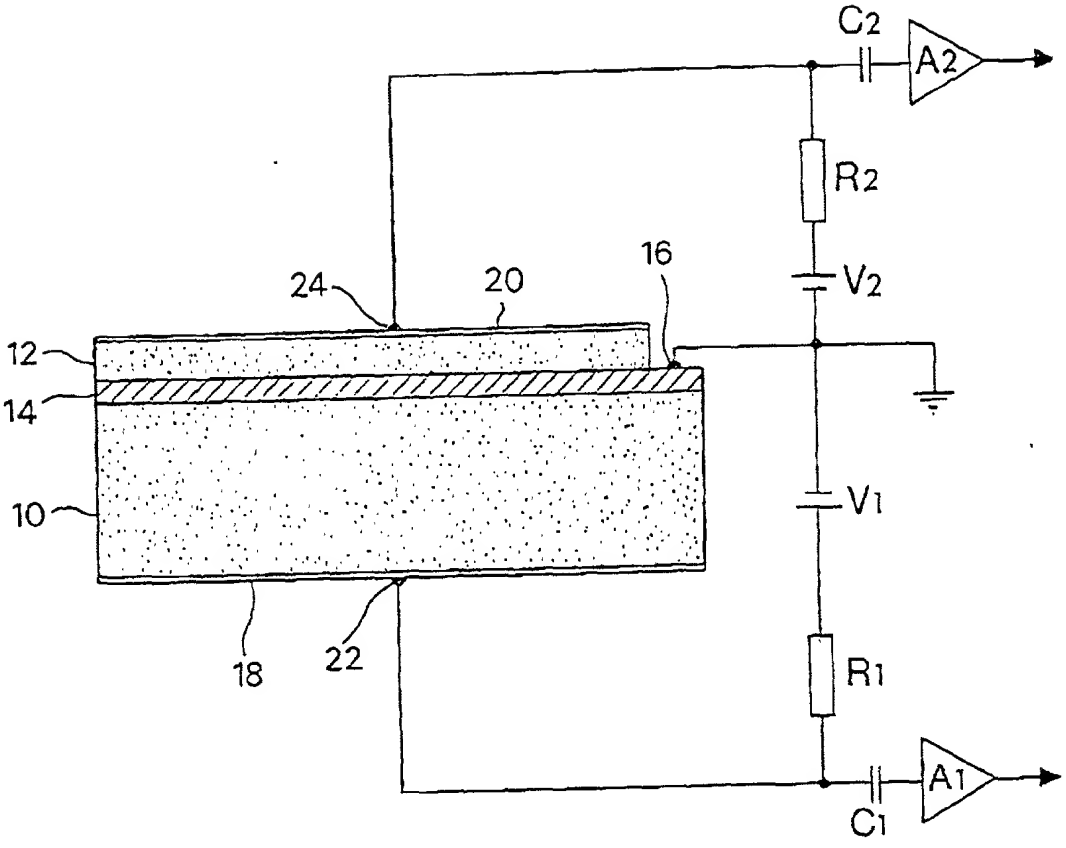

Docket No.
14148

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled "DETECTOR FOR IONISING RADIATION"

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on December 8, 2000 as United States Application No. or PCT International Application Number 09/719,242

and was amended on _____ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)			Priority Not Claimed
9812341.7 (Number)	UNITED KINGDOM (Country)	8 JUNE 1998 (Day/Month/Year Filed)	☐
(Number)	(Country)	(Day/Month/Year Filed)	☐
(Number)	(Country)	(Day/Month/Year Filed)	☐

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional

(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
PCT/IB99/01002	3 June 1999	
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

(10)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

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Form PTO-SB-01 (6-95) (Modified)
Patent and Trademark Office-U.S. DEPARTMENT OF COMMERCE

3-00

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Fourth inventor's signature Date
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Full name of fifth inventor, if any
Fifth inventor's signature Date
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Post Office Address

Full name of sixth inventor, if any
Sixth inventor's signature Date
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Citizenship
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